

**NUMERICAL STUDY ON SHEAR STRENGTHENING OF REINFORCED
CONCRETE (RC) DEEP BEAMS WITH AND WITHOUT STIRRUPS USING
NEAR-SURFACE MOUNTED FRP BARS**

MOHANAD HATEM SHADHAR

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DEDICATION

To the memory of my mother, my brother, my brothers and all people that help and supported me. To my beloved father for his constant, unconditional love during all my life. Also, to my ever-supporting supervisor Prof. Ir. Dr. Abdul Aziz Bin Abdul Samad



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ABSTRACT

Near surface mounted (NSM) technique is an emerging technique for increasing the strength of reinforced concrete (RC) members. It is applied to strengthen or repair RC members. Fibre reinforced polymers (FRP) bars are commonly used through the NSM technique to strengthen RC members. However, limited studies on NSM strengthening using FRP bars on RC deep beams are available. In this research, a numerical investigation was carried out on RC deep beams strengthened in shear with NSM-FRP bars using the ABAQUS FEA version 2017. Two studies were chosen for validation purposes. The first study consist of two control deep beams modelled with and without steel stirrups and fourteen deep beams strengthened using NSM-CFRP bars with and without steel stirrups with varying parameters of CFRP bars in four groups were strengthened or repaired using the NSM-CFRP bar technique and tested by varying two criteria and namely, spacings of 100 mm and 150 mm at orientations of $0^\circ/90^\circ$ and $45^\circ/135^\circ$. The second study involves three RC deep beams, namely one control beam and two strengthened deep beams with NSM-CFRP bars modelled without stirrups oriented at $45^\circ/135^\circ$ with spacings of 100 mm and 150 mm. After validation, it was observed that the maximum difference in shear load was +14% between FEA and experimental observations. A parametric study was carried out for thirty RC deep beams strengthened with NSM FRP bars to investigate the FRP bars involving type, diameter, orientation and spacing was also carried out. CFRP bars were most effective as they achieved a maximum improvement in shear strength of +109 %. Combination of 9 mm diameter, $45^\circ/135^\circ$ inclination angle and 75 mm spacing provides optimum improves of +149%, +163 % and +134%, respectively. Later analytical study was conducted by using parametric study results to develop an empirical equation for predicting the shear contribution by FRP bars through the NSM-FRP bar technique (V_f).

ABSTRAK

Teknik Pemasangan Permukaan (NSM) adalah teknik untuk meningkatkan kekuatan anggota konkrit bertulang (RC). Disamping itu, teknik ini juga boleh digunakan untuk mengukuh atau membaikpulih anggota RC. Kebiasaannya teknik NSM akan di bina bersama bar polimer bertulang gentian (FRP) sebagai bahan untuk mengukuh anggota RC. Walau bagaimanapun, kajian mengenai pengukuhan rasuk dalam RC melalui teknik NSM dengan bar FRP (NSM-FRP) adalah terhad. Dalam penyelidikan pengukuhan ricihan rasuk dalam RC dengan teknik NSM-FRP bar, kajian kaedah berangka melalui perisian ABAQUS FEA versi 2017 telah dijalankan. Untuk tujuan pengesahan kajian berangka ini, pemilihan terhadap dua kajian yang lepas telah dilaksanakan. Kajian pertama terdiri daripada dua rasuk kawalan masing-masing dengan perangkai ricih dan tanpa perangkai ricih telah di bangunan.. Disamping itu, empat belas rasuk dalam RC dengan perangkai rich dan tanpa perangkai ricih yang telah di kukuhkan dengan teknik NSM bersama parameter CFRP bar yang berbeza telah di bangunan dan di asingkan dalam empat kumpulan terdiri dari rasuk dalam yang telah di kukuh atau di baikpulih menggunakan teknik NSM-CFRP bar dengan dua kriteria iaitu perangkai ricih pada jarak 100 mm dan 150 mm, dan perangkai ricih pada orientasi $0^{\circ}/90^{\circ}$ dan $45^{\circ}/135^{\circ}$. Kajian kedua melibatkan tiga rasuk dalam RC iaitu satu rasuk kawalan dan dua rasuk dalam tanpa perangkai ricih yang telah diperkukuh dengan teknik NSM-CFRP bar berorientasi pada $45^{\circ}/135^{\circ}$ dengan jarak 100 mm dan 150 mm. Selepas pengesahan antara kajian berangka dan pemilihan dua kajian yang lepas dijalankan, perbezaan maksimum beban ricih yang diperhatikan adalah sebanyak +14%. Kajian parametrik bar FRP pelbagai jenis, diameter, orientasi dan jarak juga telah dilakukan. Hasil kajian parametrik telah menunjukkan jenis CFRP merupakan bar paling berkesan apabila mencapai peningkatan maksimum daya ricih sebanyak +109%. Mana kala gabungan diameter 9 mm, sudut orientasi bar $45^{\circ}/135^{\circ}$ dan jarak pada 75 mm memberikan peningkatan optimum masing-masing pada + 149%, +163% dan +134%. Akhirnya, melalui kajian analitik satu persamaan empirikal yang

meramalkan sumbangan daya ricih bar FRP melalui teknik NSM-FRP (V_f) telah berjaya dibangunkan.



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PERPUSTAKAAN TUNKU TUN AMINAH

TABLE OF CONTENTS

TITEL	i
DECLARATION	ii
DEDICATION	iii
ACKNOWLEDGMENT	iv
ABSTRACT	v
ABSTRAK	vi
TABLE OF CONTENTS	viii
LIST OF TABLES	xiv
LIST OF FIGURES	xvii
LIST OF SYMBOLS AND ABBREVIATIONS	xxxii
 CHAPTER 1 INTRODUCTION	 1
1.1 Research Background	1
1.2 Problem statement	4
1.3 Objectives of the research	5
1.4 Scopes of the Research	5
1.5 Significance	7
1.6 Layout of Thesis	8
 CHAPTER 2 LITERATURE REVIEW	 10
2.1 Introduction	10
2.2 Fiber reinforced polymer (FRP)	11

2.2.1	Typical available FRP products used in civil engineering	12
2.2.2	Type of FRPs	13
2.2.2.1	Aramid fiber reinforced polymer (AFRP)	13
2.2.2.2	Carbon fiber reinforced polymer (CFRP)	14
2.2.2.3	Glass fiber reinforced polymer (GFRP)	14
2.2.2.4	Basalt fiber reinforced polymer (BFRP)	15
2.2.3	Mechanical Properties of FRP	16
2.3	Techniques used to strength RC members using FRP materials	19
2.3.1	Externally bonded of FRP materials technique (EB)	19
2.3.2	Embedded Through-Section FRP Rod (ETS)	20
2.3.3	Near-surface mounted technique (NSM FRP)	21
2.4	Deep beams	23
2.4.1	Introduction	23
2.4.2	Shear behaviour in RC deep beam without stirrups	24
2.4.3	Mechanisms of shear transfer	25
2.4.3.1	Shear stresses in un-cracked concrete	26
2.4.3.2	The aggregate interlock	27
2.4.3.3	Dowel action longitudinal reinforcement	27
2.4.3.4	Residual tensile strength across cracks	28
2.4.3.5	Arch action	29



2.4.4	Type of shear failure in RC deep beams	29
2.4.4.1	Shear tension failure	30
2.4.4.2	Shear compression failure	30
2.4.4.3	Diagonal tension failure	31
2.4.4.4	Arch rib failure	32
2.4.4.5	Shear failure by crushing web	32
2.5	Deep beam design in ACI 318-14	33
2.6	Previous experimental studies on NSM FRP	34
2.7	Finite element modelling	48
2.7.1	Selection of Finite Element Analysis (FEA) Software	49
2.7.2	Implicit vs Explicit analysis	54
2.7.3	Element types	54
2.7.3.1	Continuum elements	55
2.7.3.2	Shell element	57
2.7.3.3	Beam element	57
2.7.3.4	Truss elements	58
2.7.4	Modelling of concrete material using concrete damage plasticity	58
2.7.5	Compressive behaviour for concrete damaged plasticity	61
2.7.5.1	Desayi & Krishnan, (1964) model	61
2.7.6	Plasticity parameters of concrete damage plasticity	62
2.7.6.1	Abilities of concrete damage plasticity model	66
2.7.7	Previous research by using concrete damage plasticity	66
2.7.8	Modelling of concrete- epoxy interface	68
2.7.9	Numerical studies on beams strengthened with NSM FRP	71



2.8	Shear contribution of FRP in codes and previous studies	78
2.8.1	fib, (2001) model	78
2.8.2	Khalifa & Nanni, (2002) model	79
2.8.3	CSA S806, (2007) code	80
2.8.4	(ACI 440.2R-08) Code	80
2.8.5	Dias & Barros, (2008) model	81
2.8.6	Islam, (2009b) model	82
2.8.7	Fawzy, (2018) model	83
2.9	Chapter summary	84
CHAPTER 3	RESEARCH METHODOLOGY	85
3.1	Introduction	86
3.2	ABAQUS software	87
3.2.1	Modelling procedures using ABAQUS	87
3.3	Phase 1-validation from (Samad <i>et al.</i> , 2017)	89
3.3.1	Models Descriptions	90
3.3.2	Modelling and Material Properties	97
3.3.2.1	Material properties of concrete	97
3.3.2.2	Carbon fiber Reinforced Polymer	99
3.3.2.3	Steel reinforcement	99
3.3.2.4	Material properties of concrete-epoxy interface	100
3.3.3	Phase 1-validation from Ali & Mezher, (2015)	100
3.3.3.1	Material properties	102
3.3.4	Element type for (Samad <i>et al.</i> , 2017 and Ali & Mezher, 2015)	103
3.3.5	Assembly and boundary condition for (Samad <i>et al.</i> , 2017 and Ali & Mezher, 2015)	104
3.4	Phase 2-Parametric study	108
3.4.1	Modelling and Material Properties	120



PTTA
PERPUSTAKAAN TUN AMINAH

3.5	Phase 3-Modified Empirical Equation using SPSS software	120
3.6	Chapter summary	121
CHAPTER 4	NUMERICAL SIMULATION OF RC BEAMS	123
4.1	Introduction	123
4.2	Objectives	123
4.3	FEA validation from Samad <i>et al.</i> , (2017)	124
4.3.1	Meshing and convergence analysis	124
4.3.2	Validation to ultimate shear load	126
4.3.3	Validation of load versus deflection profile	132
4.3.4	Failure mode of RC deep beam models	142
4.3.5	Post cracking stages	152
4.4	Validation from (Ali & Mezher, 2015)	155
4.4.1	Load vs deflection	156
4.5	Parametric study	158
4.5.1	Parametric study on type of FRP bars	159
4.5.2	Shear load vs deflection	162
4.6	Failure mode of deep beams from parametric study	170
4.7	Effects of parameters	182
4.7.1	Effects of different types of FRP bars	1822
4.7.2	Effects of various area of FRP bars, A_f	183
4.7.3	Effects of FRP bars inclination, α	185
4.7.4	Effects of spacing between FRP bars, S_f	186
4.8	Summary	187
CHAPTER 5	DEVELOPMENT OF EMPIRICAL EQUATION	190
5.1	Introduction	190
5.2	Comparison of results from FEA and empirical equations	191
5.3	Proposed empirical equation	201



PTTA AUTHM
PERPUSTAKAAN TUNKU TUN AMINAH

5.3.1	Proposed equations of effective strain, $\epsilon_{ef prop}$	202
5.3.2	Comparison of FEA results with proposed equations, $\epsilon_{ef prop}$	202
5.3.3	Proposed empirical equation $V_{f prop}$	207
5.3.4	Comparison of FEA results with proposed equation, $V_{f prop}$	208
5.4	Parameters affecting on shear strength	212
5.4.1	Influence of various type of FRP bars	212
5.4.2	Influence of FRP bars area, A_f	214
5.4.3	Influence of angle of FRP inclination, α	216
5.4.4	Influence of spacing between FRP bars, S_f	218
5.5	Summary	219
CHAPTER 6 CONCLUSION AND RECOMMENDATIONS		220
6.1	Overview	220
6.2	Conclusion for objectives	221
6.2.1	Validation from previous experimental observation	221
6.2.2	The effectiveness of mechanical and geometrical properties FRP bars	221
6.2.3	The effectiveness of inclination and spacing of FRP bars	222
6.2.4	Analytical investigation and propose empirical equation	222
6.3	Contribution of the research	223
6.4	Recommendations	223
REFERENCES		225
APPENDIX A		239
APPENDIX B		245
APPENDIX C		250



PTTA UTHM
PERPUSTAKAAN TUNJUNGAN AMINAH

LIST OF TABLES

2.1	Properties of various types of fibres (Sonnenschein <i>et al.</i> , 2016)	17
2.2	The differences between FRP and steel (Teng <i>et al.</i> , 2000)	19
2.3	Details of RC beams strengthened in shear with EB, NSM and ETS (Morsy <i>et al.</i> , 2011)	38
2.4	Control and strengthened RC beams detailing (Jalali <i>et al.</i> , 2012)	39
2.5	Strengthening configurations of strengthened beams (Singh <i>et al.</i> , 2013)	40
2.6	Summary of experimental results in (Ali & Mezher, 2015)	43
2.7	Details of experimental results in (Samad <i>et al.</i> , 2017)	46
2.8 (a)	The constitutive relations of concrete from various software (Johnson <i>et al.</i> , 2006)	50
2.8 (b)	The cracking model and shear strength check from various software (Johnston <i>et al.</i> , 2006)	51
2.9	Comparison of steel reinforcement response with various software (Johnson <i>et al.</i> , 2006)	52
2.10	Differences between ABAQUS/Standard and ABAQUS/Explicit (ABAQUS 2010)	53
2.11	Concrete damaged plasticity model parameters (Mokhatar & Abdullah, 2012)	67
2.12	Concrete damaged plasticity model parameters Rahman <i>et al.</i> (2019)	68

3.1	Description of all models	96
3.2	Plasticity Parameters for Concrete Damage Plasticity (Jankowiak & Lodygowski, 2005)	98
3.3	Concrete Yield Stress and Corresponding Inelastic Strain Values for (Samad <i>et al.</i> , 2017)	98
3.4	Properties of steel bars (Samad <i>et al.</i> , 2017)	100
3.5	Mechanical properties of interface layer	100
3.6	All RC deep beams models detailed (Ali & Mezher, 2015)	102
3.7	Concrete Yield Stress and Corresponding Inelastic Strain Values (Singh <i>et al.</i> , 2013)	103
3.8	Material Properties of Concrete, CFRP, and Epoxy Used (Ali & Mezher, 2015)	103
3.9	Elements used for each part of RC deep beam	104
3.10	A parametric study models details	109
3.11	Material properties of FRP bars used in the parametric study	120
4.1	A convergence study on R1 model	126
4.2	Ultimate shear load carrying capacity of control and strengthened RC deep beams	129
4.3	Comparison between FEM results and experimental observations	156
4.4	Parametric study considered for RC deep beams strengthened in shear with NSM-FRP bars	159
4.5	Ultimate shear load carrying capacity for the strengthened RC deep beams in parametric study	161
4.6	Ultimate load carrying capacity and shear contribution of RC deep beams with parametric study F	183
4.7	Ultimate load carrying capacity and shear contribution of RC deep beams with parametric study A	184



4.8	Ultimate load carrying capacity and shear contribution of RC deep beams with parametric study I	185
4.9	Ultimate load carrying capacity and shear contribution of RC deep beams with parametric study S	187
5.1	Comparison of shear contribution of NSM FRP bars in beams with steel stirrups between FEA results and different theoretical models	194
5.2	Comparison of shear contribution by NSM FRP bars in beams without steel stirrups between FEA results and different theoretical models	196
5.3	Comparison of FEA and fib results versus the values of Equation 5.3 for RC deep beams with stirrups	204
5.4	Comparison of FEA and fib result versus Equation 5.4 values for RC deep beams without stirrups	205
5.5	Comparisons of FEA results versus developed equation values for RC deep beams with and without stirrups	209
C.1	compression of proposed equation V_{fprop} with the available experimental works	252



LIST OF FIGURES

2.1	Formation of Fibre Reinforced Polymer Composites bars (Jones, 2014)	12
2.2	Stress-strain relationship for resin, fibre and FRP composite (ISIS M03, 2007)	12
2.3	Various FRP products: (a) FRP bars and (b) FRP sheets/laminates (fib,2007)	13
2.4	Unidirectionally reinforced composite FRP bar with main material axes:1(L) -longitudinal direction; 2(T), 3(T) -transverse directions (fib,2007)	16
2.5	Typical Stress-strain relation FRPs composites in Comparison with steel reinforcement (Carolín, 2003)	18
2.6	Wrapping schemes of externally bonded FRP technique (EB) (Belarbi & Acun, 2013)	20
2.7	FRP bars embedded through section procedure (ETS) (Morsy et al., 2012)	21
2.8	Use of NSM with various types of FRP bars and strips (De Lorenzis & Teng, 2007)	22
2.9	Plane stress state of one point and the Mohr's circle (Beer & Johnson ,1992)	24
2.10	Types of inclined cracks (Hawkins, 2005)	25
2.11	Shear transfer actions contributing to shear resistance (Abdul-Salam, 2014)	26
2.12	Dowel action a) failure modes of the mechanism due to dowel force D; (b) stress distribution over the width b	

	within a section; (c) stress distribution along a dowel (Vintzileou, 1997)	28
2.13	Arch mechanism in deep beams (Gregor <i>et al.</i> , 1997)	29
2.14	Shear tension failure mode (Devadas, 2003)	30
2.15	Shear compression failure mode (Devadas, 2003)	31
2.16	Diagonal tension failure (Devadas, 2003)	31
2.17	Arch rib failure (Devadas, 2003)	32
2.18	Failure due to crushing web (Devadas, 2003)	33
2.19	a) plan and cross section of RC beams b) shear strengthening of RC beams with NSM CFRP bars Islam <i>et al.</i> (2009b)	35
2.20	Detailing for shear strengthening of RC beams with NSM-CFRP bars & NSM steel bars (Rahal, 2010)	37
2.21	Cross section of RC beams with shear reinforcement detailing (Morsy <i>et al.</i> , 2011)	38
2.22	(a) Cross section and reinforcement details of RC beams and fabrication of manually made CFRP rods: (b) perpendicular anchors; (c) 45 inclined anchors (d) straight bar (Jalali <i>et al.</i> , 2012)	39
2.23	a) Cross-section and reinforcement detailing b) Various strengthening patterns of RC beams (Singh <i>et al.</i> , 2013)	41
2.24	a) Test setup b) shear and bending strengthening pattern of RC beams with NSM CFRP (Almassri <i>et al.</i> , 2015)	42
2.25	Shear strengthening of RC beams with NSM CFRP laminates (Kuntal <i>et al.</i> , 2017)	45
2.26	(a) control beam (b) strengthened beam with NSM CFRP vertical bars	



PTT AUTHM
PERPUSTAKAAN TUNJUNGAN AMINAH

	(c) strengthened beam with NSM CFRP inclined bars (d) strengthened beam with NSM CFRP horizontal bars (Fawzy, 2018)	48
2.27	Common element families in ABAQUS (ABAQUS,2010)	55
2.28	(a) Linear brick, (b) quadratic brick and (c) modified tetrahedral elements (ABAQUS,2010)	56
2.29	Integration point scheme in hexahedral elements (ABAQUS, 2010)	56
2.30	Response of concrete under uniaxial tension (ABAQUS, 2010, Jankowiak <i>et al.</i> ,2005 and Kmiecik & Kamiński, 2011)	60
2.31	Response of concrete to uniaxial loading in compression (ABAQUS, 2010, Jankowiak <i>et al.</i> ,2005 and Kmiecik & Kamiński, 2011)	60
2.32	The stress-strain curve for concrete under uniaxial compression for (Desayi & Krishnan, 1964) model	62
2.33	The hyperbolic potentials in the meridional stress plane (ABAQUS, 2010 and Kmiecik & Kamiński, 2011)	63
2.34	Deviatoric cross section of failure surface in concrete damaged plasticity model plane (ABAQUS, 2010 and Kmiecik & Kamiński, 2011)	64
2.35	Yield surface in plane stress (ABAQUS,2010)	65
2.36	Mechanism of the traction-separation response (ABAQUS,2010)	69
2.37	Typical finite-element mesh and bond system (Coronado & Lopez, 2009)	72
2.38	The mesh of an FE model (Omran & El-Hacha, 2011b)	73



2.39	a) FE mesh of the model, b) peeling-off crack initiation zone (Radfar <i>et al.</i> , 2012)	74
2.40	a) horizontal pattern of CFRP strips b) vertical pattern c) ring type pattern d) mesh of model (Kassim <i>et al.</i> , 2015)	75
2.41	Boundary conditions and mesh formation on one half of the beams (Mostofinejad <i>et al.</i> , 2019)	77
3.1	Methodology of research	86
3.2	Flow chart of FE analysis using ABAQUS	88
3.3	Groups classification of beams of the validation study (Samad <i>et al.</i> , 2017)	90
3.4	Control RC deep beam R1 (with stirrups)	91
3.5	Control RC deep beam R2 (without stirrups)	91
3.6	RC deep beam G1S1 initially strengthened by NSM CFRP bars spaced at 100 mm with 0°/90° orientation	92
3.7	RC deep beam G1S2 initially strengthened by NSM CFRP bars spaced at 150 mm with 0°/90° orientation	92
3.8	RC deep beam G1S3 initially strengthened by NSM CFRP bars spaced at 100 mm with 45°/135° orientation	92
3.9	RC deep beam G1S4 initially strengthened by NSM CFRP bars spaced at 150 mm with 45°/135° degree orientation	93
3.10	RC deep beam G2S1 initially strengthened by NSM CFRP bars spaced at 100 mm with 0°/90° orientation	93
3.11	RC deep beam G2S2 initially strengthened by NSM CFRP bars spaced at 150 mm with 0°/90° orientation	93



3.12	RC deep beam G2S3 initially strengthened by NSM CFRP bars spaced at 150 mm with 45°/135° orientation	94
3.13	RC deep beam G2S4 initially strengthened by NSM CFRP bars spaced at 150 mm with 45°/135° orientation	94
3.14	RC deep beam G3S1 pre cracked and repaired by NSM CFRP bars spaced at 100 mm with 0°/90° orientation	94
3.15	RC deep beam G3S2 pre cracked and repaired by NSM CFRP bars spaced at 150 mm with 0°/90° orientation	95
3.16	RC deep beam G3S3 pre cracked and repaired by NSM-CFRP bars spaced at 100 mm with 45°/135° degree orientation	95
3.17	RC deep beam G3S4 pre cracked and repaired by NSM CFRP bars spaced at 150 mm with 45°/135° orientation	95
3.18	RC deep beam G4S1 initially strengthened by CFRP NSM anchoring bars spaced at 100 mm c/c with 0°/90° orientation	96
3.19	RC deep beam G4S2 initially strengthened by CFRP NSM anchoring bars spaced at 150 mm c/c with 0°/90° degree orientation	96
3.20	Tensile test of CFRP bar (Samad <i>et al.</i> , 2017)	99
3.21	Control RC deep beam C1 (without stirrups)	101
3.22	RC deep beam CS150 initially strengthened by NSM-CFRP bars spaced at 150 mm with 45°/135° orientation	101
3.23	RC deep beam CS100 initially strengthened by NSM-CFRP bars spaced at 100 mm with 45°/135° orientation	102
3.24	Final assembly of the beam (G1S1)	106



3.25	Embedded constrain for steel and FRP of the RC deep beam (G1S1)	106
3.26	Cohesive interface assigned regions of the RC deep beam (G1S1)	107
3.27	Points of loading and boundary conditions	107
3.28	The nomenclature of models in parametric study	109
3.29	RC deep beam F-DB-CF with stirrups strengthened by NSM-CFRP bars spaced at 150 mm with 0°/90° orientation	110
3.30	RC deep beam F-DB-CF without stirrups strengthened by NSM-CFRP bars spaced at 150 mm with 0°/90° orientation	110
3.31	RC deep beam F-DB-AF with stirrups strengthened by NSM-AFRP bars spaced at 150 mm with 0°/90°orientation	110
3.32	RC deep beam F-DB-AF without stirrups strengthened by NSM-AFRP bars spaced at 150 mm with 0°/90°orientation	111
3.33	RC deep beam F-DB-GF with stirrups strengthened by NSM-GFRP bars spaced at 150 mm with 0°/90°orientation	111
3.34	RC deep beam F-DB-GF without stirrups strengthened by NSM-GFRP bars spaced at 150 mm with 0°/90° orientation	111
3.35	RC deep beam A-DB-5d with stirrups strengthened by NSM-CFRP bars spaced at 150 mm with 0°/90° orientation	112
3.36	RC deep beam A-DB-5d without stirrups strengthened by NSM-CFRP bars spaced at 150 mm with 0°/90° orientation	112



PTTA UNIVERSITI
PERPUSTAKAAN TUN AMINAH

3.37	RC deep beam A-DB-6d with stirrups strengthened by NSM-CFRP bars spaced at 150 mm with 0°/90° orientation	112
3.38	RC deep beam A-DB-6d without stirrups strengthened by NSM-CFRP bars spaced at 150 mm with 0°/90° orientation	113
3.39	RC deep beam A-DB-9d with stirrups strengthened by NSM-CFRP bars spaced at 150 mm with 0°/90° orientation	113
3.40	RC deep beam A-DB-9d without stirrups strengthened by NSM-CFRP bars spaced at 150 mm with 0°/90° orientation	113
3.41	RC deep beam I-DB-90° with stirrups strengthened by NSM-CFRP bars spaced at 100 mm with 0°/90° orientation	114
3.42	RC deep beam I-DB-90° without stirrups strengthened by NSM-CFRP bars spaced at 100 mm with 0°/90° orientation	114
3.43	RC deep beam I-DB-45° with stirrups strengthened by NSM-CFRP bars spaced at 100 mm with 45°/135° orientation	114
3.44	RC deep beam I-DB-45° without stirrups strengthened by NSM-CFRP bars spaced at 100 mm with 45°/135° orientation	115
3.45	RC deep beam I-DB-60° with stirrups strengthened by NSM-CFRP bars spaced at 100 mm with 60°/120° orientation	115
3.46	RC deep beam I-DB-60° without stirrups strengthened by NSM-CFRP bars spaced at 100 mm with 60°/120° orientation	115
3.47	RC deep beam I-DB-30° with stirrups strengthened by NSM-CFRP bars spaced at 100 mm with 30°/150° orientation	116



3.48	RC deep beam I-DB-30° without stirrups strengthened by NSM-CFRP bars spaced at 100 mm with 30°/150° orientation	116
3.49	RC deep beam S-DB-75 with stirrups strengthened by NSM-CFRP bars spaced at 75 mm	116
3.50	RC deep beam S-DB-75 without stirrups strengthened by NSM-CFRP bars spaced at 75 mm	117
3.51	RC deep beam S-DB-100 with stirrups strengthened by NSM-CFRP bars spaced at 100 mm	117
3.52	RC deep beam S-DB-100 without stirrups strengthened by NSM-CFRP bars spaced at 100 mm	117
3.53	RC deep beam S-DB-125 without stirrups strengthened by NSM-CFRP bars spaced at 125 mm	118
3.54	RC deep beam S-DB-125 without stirrups strengthened by NSM-CFRP bars spaced at 125 mm	118
3.55	RC deep beam S-DB-150 with stirrups strengthened by NSM-CFRP bars spaced at 150 mm	118
3.56	RC deep beam S-DB-150 without stirrups strengthened by NSM-CFRP bars spaced at 150 mm	119
3.57	RC deep beam S-DB-175 with stirrups strengthened by NSM-CFRP bars spaced at 175 mm	119
3.58	RC deep beam S-DB-175 without stirrups strengthened by NSM-CFRP bars spaced at 175 mm	119



3.59	Flow diagram of developing equation	121
4.1	Mesh used in a model (R1)	125
4.2	Mesh convergence study of FEA for the beam R1	126
4.3	Comparison of shear load between experimental and FEM	131
4.4	Comparison of mid-span deflection between test and FEM	132
4.5	Shear load vs deflection for control beams R1&R2	133
4.6	Shear load vs deflection for strengthened beams in Group1	135
4.7	Shear load vs deflection for strengthened beams in Group2	138
4.8	Shear load vs deflection for pre cracked and repaired beams in Group3	139
4.9	Shear load vs deflection for strengthened beams in Group4	140
4.10	Comparison between experimental cracking pattern and damage behavior in FEA for (a) control RC deep beam R1 and (b) control RC deep beam R2	144
4.11	Comparison between experimental and FEA crack pattern and damage behavior for the RC deep beams in Group 1- (a) RC deep beam G1S1 and (b) RC deep beam G1S2	145
4.11(cont)	Comparison between experimental cracking pattern and damage behavior in FEA for the beams in Group 1- (a) RC deep beam G1S3 and (b) RC deep beam G1S4	146
4.12	Comparison between experimental cracking pattern and damage behavior in FEA for the	



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